Estimating RUSLE's rainfall factor in the part of Italy with a Mediterranean rainfall regime

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Abstract

The computation of the erosion index (*EI*), which is basic to the determination of the rainfall-runoff erosivity factor *R* of the Revised Universal Soil Loss Equation (RUSLE), is tedious and time-consuming and requires a continuous record of rainfall intensity. In this study, a power equation ($r^2 = 0.867$) involving annual erosion index ($EI_{30\text{-annual}}$) in the Mediterranean part of Italy is obtained. Data from 12 raingauge stations are used to derive and then test a regional relationship for estimating the erosion index from only three rainfall parameters. Erosivity rainfall data derived from 5 additional stations are used for validation and critical examination. The empirical procedures give results which compare satisfactorily with relationships calibrated elsewhere.

Keywords: erosion index, rainfall, erosivity, Revised Universal Soil Loss Equation

Introduction

The Mediterranean environment is known not only for its limited water availability but also for flood events and for rainfall erosion under several land usages (Kosmas *et al*., 1997). Empirical and process-based soil erosion models use rain as the rainfall–runoff erosivity index. In modelling sheet and rill erosion with RUSLE (Renard *et al*., 1997), the rainfall–runoff erosivity factor (*R*) quantifies the effect of raindrop impact and reflects the amount and rate of runoff likely to be associated with rain. To obtain an *R*-value by the RUSLE methodology, high resolution rainfall measurements at a small time step are required as well as accurate computation of the rainfall erosivity (EI_{30}) of each storm. Where such data are not available, alternative procedures are suggested in the USLE and RUSLE handbooks. The present study, therefore, seeks to estimate the *R*-factor from more readily available types of precipitation data such as mean monthly or annual totals. In Hawaii, for example, Lo *et al*. (1985) found a correlation between mean annual rainfall and *R*. In the USA, Renard and Freimund, (1994), used both mean annual precipitation and the Modified Fournier Index (Arnoldus, 1977) to estimate the *R*-factor. Similar approaches have been proposed for Belgium (Bollinne *et al*., 1979), Bavaria (Rogler and Schwertmann, 1981) and south-eastern Australia (Yu and Rosewell, 1996). Recently, de Santos Loureiro and de Azevedo Coutinho (2001) estimated the EI_{30} index, from monthly rainfall data for the south of Portugal. In the European Report on Soil Erosion in Italy, van der Knijff *et al*., (2000) applied a relationship, based on the mean annual precipitation, to estimate the *R*-factor; it was calibrated in Tuscany and extrapolated to the whole of Italy, with uncertain results as seen in the conclusions in the report.

This paper describes a new procedure for estimating the RUSLE EI_{30} parameter, on an annual time scale. All procedures are illustrated using rainfall data from the peninsular region of Italy with a Mediterranean rainfall regime.

Study area and available data

Italy lies at the centre of the Mediterranean and so suffers strongly from the perturbing action of the sea. This, together with the Apennines mountain ridge system and isolated relief, influences the particular characteristics of climate and weather at spatial scales from the micro-scale to the synoptic. The climate shows marked Mediterranean characteristics

Fig. 1. *Location of the study area and positions of the raingauge stations using for analysis (squares) and for validation (triangles).*

along the coastal zones, changing to almost continental conditions inland, so that a dry summer period is followed by maximum rainfall in the mid-autumn and a gradual lessening of rainfall in autumn and spring. Although there are extreme rainfall events in winter, stormy events with the highest hourly and half-hourly intensities occur between May and September (Diodato, 1999). In this study, twelve raingauge stations in peninsular Italy, where the rainfall regime is Mediterranean, were used and five additional stations validated the results (Fig. 1). Northern Italy was excluded because the rainfall regime there is different from that elsewhere in Italy.

Table 1 summarises: code number, latitude, longitude, altitude and length of record, for each station. Figure 2 indicates the inter-annual variability of annual precipitation and erosion index for stations representative of peninsular Italy. The relationship between the annual rainfall and erosivity is similar only in some years; this confirms the extreme variability of rainfall patterns in Mediterranean areas (Renschler *et al.,* 1999; Le Bissonnais *et al*., 2002; Renschler and Harbor, 2002), with wide and unpredictable rainfall fluctuations from year to year. Extreme rainstorm characteristics for 1989, 1995, 1997 and 1999–2001 differ from those for other years, although annual precipitation totals were similar in general. However, as the erosion index is not always distributed in proportion to precipitation, assessment of soil erosion hazards requires knowledge of the annual distribution of EI_{30}.

Development of simplified methods for evaluating the annual erosive index

The rainfall factor R is a numerical descriptor of the ability of rainfall to erode soil (Wischmeier and Smith, 1959). For a given location, it is the long-term average of the annual R_{aj} values which, in turn, are given by the sum of all the erosion index (EI) single-storm EI_{30} values for year j. The EI calculation requires a very onerous procedure, involving the analysis of the hyetograph for every rain event >13mm over a 22-yr period (Wischmeier and Smith, 1978) and at

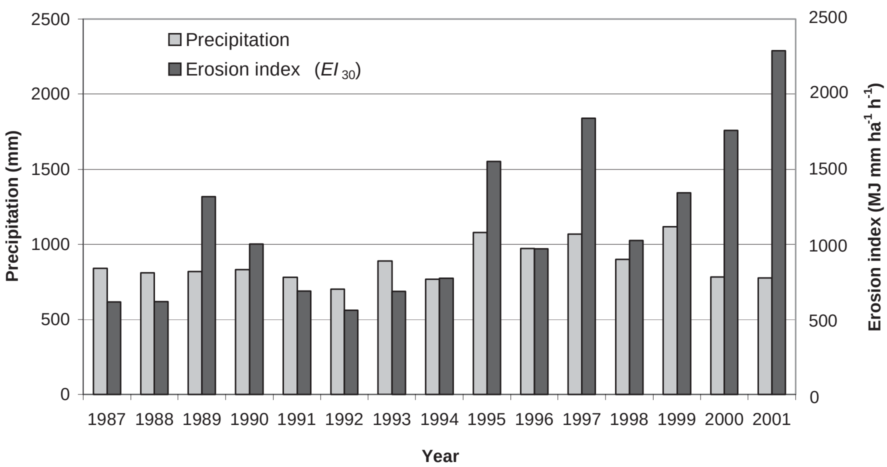

Fig. 2. *Annual precipitation and erosion index, based on RUSLE methodology, for Benevento – Monte Pino Observatory (Middle Italy).*

Table 1. Characteristics of the Italian raingauge stations used to derive the simplified relationship for estimating *EI* (interpolation) and of the additional stations used for testing (validation).

Raingauge stations	*Latitude Northing*	*Longitude Easting*	*Elevation (m)*	*Length ofRecord (years)*	*Network*
INTERPOLATION					
Aliano	40° 39'	16° 19'	250	2	RAN
Campochiaro	41° 28'	14° 32'	502	8	RAN
Caprarola	42° 20'	12° 11'	650	8	RAN
Castel di Sangro	41° 45'	14° 06'	810	3	RAN
Marsciano	43° 00'	12° 18'	229	4	RAN
Matera	40° 39'	16° 37'	370	1	RAN
Monsampolo	42° 53'	13° 48'	43	7	RAN
Monte Pino	41° 06'	14° 45'	184	6	CFMI
Palo del Colle	41° 03'	16° 38'	191	7	RAN
Piano Cappelle	41° 07'	14° 50'	240	8	RAN
San Casciano	43° 40'	11° 09'	230	8	RAN
Santa Fista	43° 31'	12° 08'	311	8	RAN
VALIDATION					
Libertinia	37° 33'	14° 35'	183	6	RAN
Montevergine	40° 56'	14° 43'	1270	5	CFMI
Pietranera	37° 30'	13° 31	158	6	RAN
Pontecagnano	40° 37'	14° 52'	29	5	RAN
SantaLucia	39° 59'	08° 37'	14	6	RAN

RAN = Rete Agrometeorologica Nazionale
CFMI = Centro Funzionale Monitoraggio Idropluviometrico

least 6 hours distant from the previous or the following events, but including showers of at least 6.35 mm in 15minutes.

For each erosive storm between January 1994 and December 2001, data from raingauge networks operated in peninsular Italy by RAN (Rete Agrometeorologica Nazionale – Ministero Politiche Agricole and Forestali) and CFMI (Centro Funzionale Monitoraggio Idropluviometrico – Regione Campania), were used to compute values of EI_{30} according to the RUSLE handbook instructions (Renard *et al*., 1997). On an annual basis, the EI_{30} values were taken to be the summation of values over the storms in an individual year. In addition, three rainfall variables, annual precipitation (*a*), annual maximum daily precipitation (*b*) and annual maximum hourly precipitation (*c*) were derived from the rainfall dataset. It includes 12 stations and a total of 96 years, or 69 years after the elimination of incomplete years of data. In relation to this dataset, regression equations between the annual erosion index and different rainfall variables were computed. The results make sense, because *b* and *c* are descriptors of extreme rainfalls in storms and heavy showers, which are very erosive. The variable *a*, is representative of less-erosive precipitation but its effect will be cumulative over a longer time period (one year). The use of this variable was previously suggested by FAO (1976). The power equation obtained using the data set for 69 years was:

$$EI_{30-\text{annual}} = 12.142 \cdot (abc)^{0.6446} \qquad (1)$$

where $EI_{30\text{-annual}}$ (in MJ mm ha^{-1} h^{-1}) is the annual erosive empirical index ($r^2 = 0.867$ significant at $p = 0.01$); the *a*, *b* and *c* variables are expressed in cm. The application of Eqn. (1) requires knowledge of only three annual variables, that are reported in Italian Idrographic Service newsletters.

So that average annual total of the storm *EI* values (*R*-factor) may be computed as:

$$R = \frac{1}{\mathrm{N}} \sum_{1}^{\mathrm{N}} EI_{30-\text{annual}} \qquad (2)$$

where N is the year period. Because of apparent cyclical patterns in rainfall data, Wischmeier and Smith (1978) published values for rainfall erosion indices based on station rainfall records for 22 years. Longer records are advisable, especially when the coefficient of variation of annual precipitation is large, as mentioned by Renard *et al*. (1997) in Agriculture Handbook No. 703.

Validation of the $EI_{30\text{-annual}}$ with a new data set and critical examination

To examine whether Eqn. (1), calibrated on Italian peninsular data, can be applied to a larger area, five additional stations were considered. A further test of the $EI_{30\text{-annual}}$ model was made using data from research stations at S. Lucia in Sardinia, Libertinia and Pietranera in Sicily, Pontecagnano on the coast and Montevergine in the Apennines of the Campania. The reduced major-axis regression lines for erosion index show 1:1 relationships between measured and estimated values (Fig. 3). In addition, for each additional raingauge station, the applicability of the equations derived from data from other areas was tested by comparing R-factor values measured with those estimated. For this purpose, three relationships, developed elsewhere were applied:

$$R = \frac{1}{\mathrm{N}}\sum_{m=1}^{12}\left(7.05 \cdot rain_{10} - 88.92 \cdot days_{10}\right) \tag{3}$$

(de Santos Loureiro and de Azevedo Couthino, 2001), where $rain_{10}$ is monthly rainfall ≥10 mm, and $days_{10}$ is monthly number of days with rainfall ≥10 mm;

$$R = 0.21 \cdot q^{-0.096} \cdot P^{2.3} \cdot NGP^{-2} \tag{4}$$

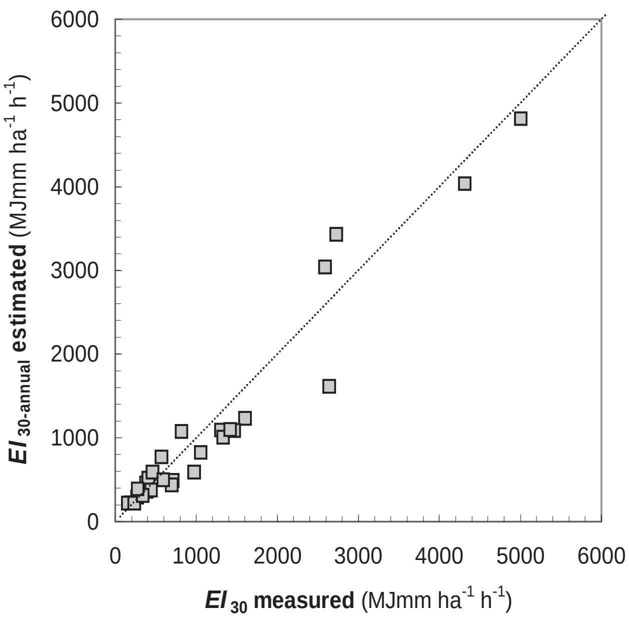

Fig. 3. *Scatter diagram between erosion index measured (RUSLE methodology) and estimated value (Eqn. 2) at the validation stations*

(D'Asaro and Santoro, 1983), where q is the elevation of the station, P is average annual precipitation in mm and NGP is average annual number of days with rainfall;

$$R = 0.0483 \cdot P^{1.61} \tag{5}$$

(Renard and Freimund, 1994).

The performance of the four different algorithms (Eqns. 2, 3, 4 and 5) was assessed by the difference between the estimated value (R) and the corresponding measured (R^*) one is the experimental error (μ):

$$\varepsilon_i = R_i - R^*_i \tag{6}$$

$$\text{Mean Absolute Errors: } \mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}\left|\varepsilon_i\right| \tag{7}$$

$$\text{Root Mean Square Errors: } \mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\varepsilon_i^{\,2}} \tag{8}$$

where n is the number of locations subjected to validation.

The results are listed in Table 2. Statistics of the experimental errors are reported in Table 3. The very largest errors are produced by Eqn.(5). Large errors are generated by Eqns. (3) and (4). The best results are generally obtained using $EI_{30\text{-annual}}$ model (Eqn. 2). There is clearly a significant improvement in the estimation performance when taking into account descriptors of the extreme rainfall (b and c variables of the Eqn. (2): the MAE decreases from 664–551 MJmm ha^{-1} h^{-1} (Eqns. 3 and 4) to 133 MJmm ha^{-1} h^{-1} (Eqn. 2). These tests indicate that the new procedure can give reasonable results in conditions ranging from the Mediterranean climate of southern Europe.

Conclusion

A simplified relationship for estimating the erosion index EI in the Mediterranean area, using rainfall data from 12 peninsular Italian locations (each with eight years' record) is proposed. Data from five additional stations in the islands of Sicily and Sardinia and south Italy were used to validate the relationship. It was established that the relationship

Table 3. Statistics of the experimental errors (MJ mm ha^{-1} h^{-1}) computed from average annual rainfall erosivity 5-data locations (see Table 2)

Equation	*2*	*3*	*4*	*5*
MAE	133	551	664	1273
RMSE	153	828	816	1852

Table 2. Comparison between EI_{30} (R-factor in MJ mm ha^{-1} h^{-1}) measured values (RUSLE methodology) and estimated values by several authors, in 1994–1999 year period.

Equation / *Raingauge station*	*Elevation* (*m*)	*Mean annual rainfall* (*mm*)	*Mean annual rainy days* (*d year*$^{-1}$)	EI_{30} *measured* R^{*}	*(2)* Diodato *in this report* R	*(3)* de Santos & de Azevedo *(2001)* R	*(4)* D'Asaro & Santoro *(1983)* R	*(5)* Renard & Freimund *(1994)* R
Libertinia	183	446	62	870	689	828	699	890
Montevergine	1273	1608	105	3214	3354	4927	3860	7016
Pietranera	158	526	67	593	561	780	887	1161
Pontecagnano	29	867	90	1148	907	1809	1826	2595
Santa Lucia	14	479	45	471	401	625	2000	998

between the annual erosivity EI_{30} and corresponding rainfall parameters can be expressed in a potential form. A regional relationship for estimating the erosion index as a function of three rainfall variables was also developed and tested. In many cases, monthly or annual rainfall amounts are not representative of an erosion index; therefore, grouping three rainfall variables on various time scales has been shown to be more successful in reproducing the annual amount of erosion.

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